Results of Examining Small Impact Crater Populations on the Moon

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NASA LUNAR SCIENCE FORUM

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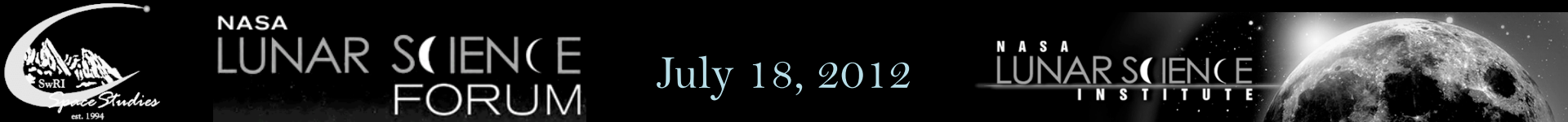
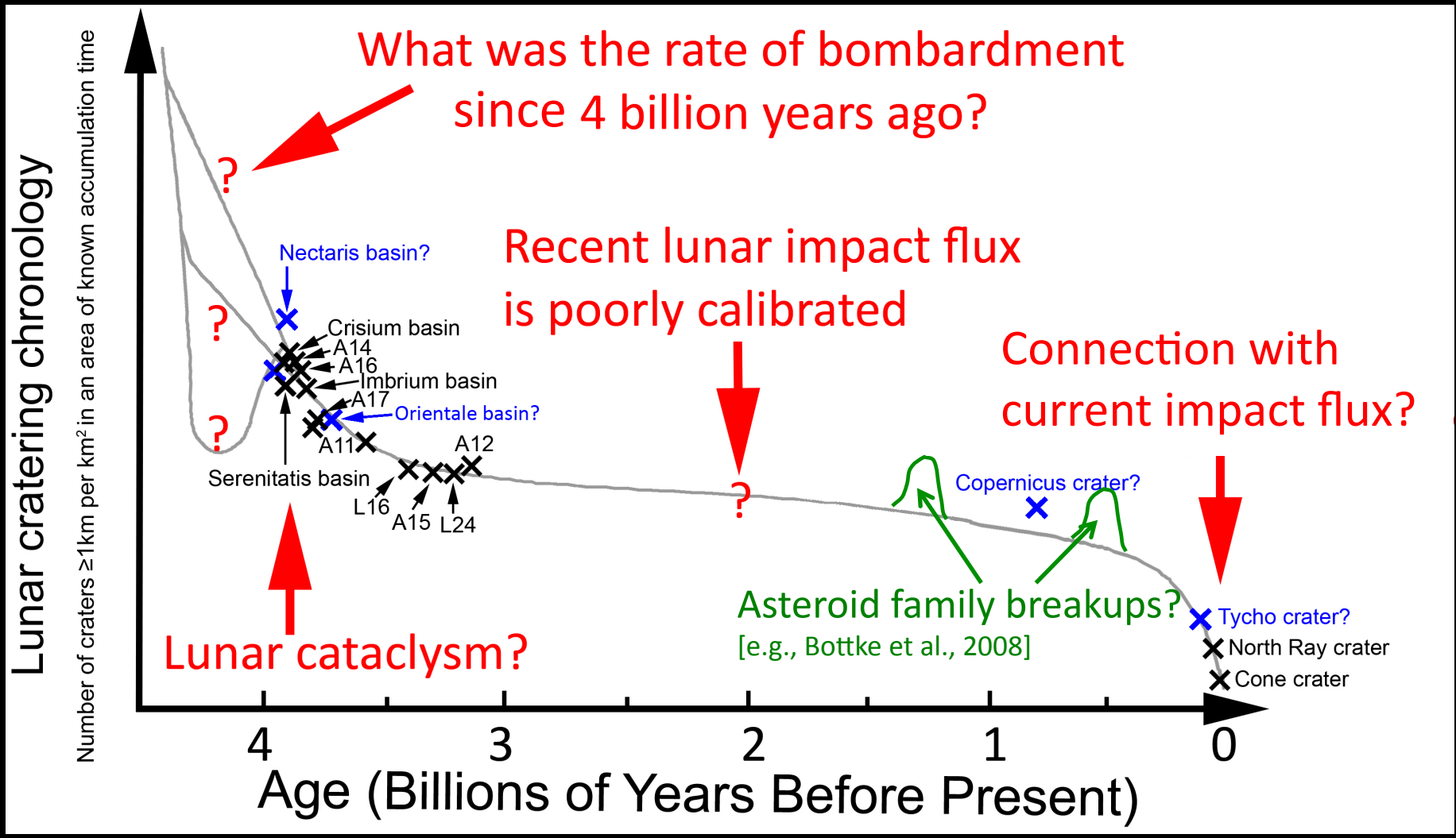


Goal: investigate lunar impactors' size-frequency distributions (SFDs) through time and improve estimates of impact rates since the LHB



Credit: Katie Joy, LPI

Motivation

» Previous work needs updating

e.g., Wilhelms et al. (1978), Hartmann et al. (1981), Neukum & Ivanov (1994)

» Little work for this age & diameter range

» Outstanding LROC imaging - WAC global mosaic

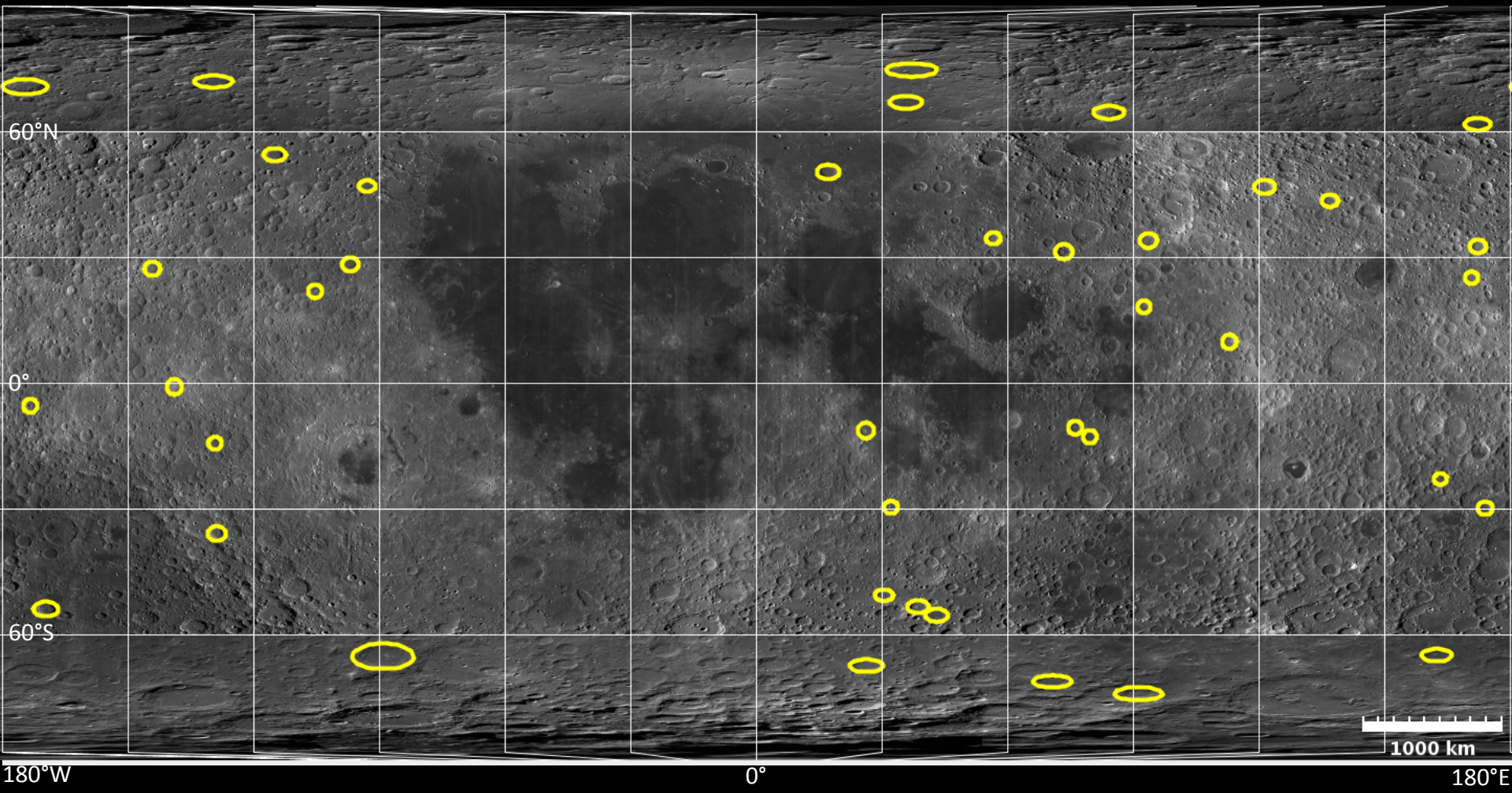
http://lroc.sese.asu.edu/

» Recent developments in numerical approaches

e.g., Bottke et al. (2000, 2002, 2005), Marchi et al. (2009)

OUR APPROACH: COMPILING AND ANALYZING SMALL, SUPERPOSED CRATER SFDS ON THE FLOORS OF SEVERAL LARGE LUNAR CRATERS

Selected Mid-Sized Craters



» Wide distribution in latitude and longitude, and age

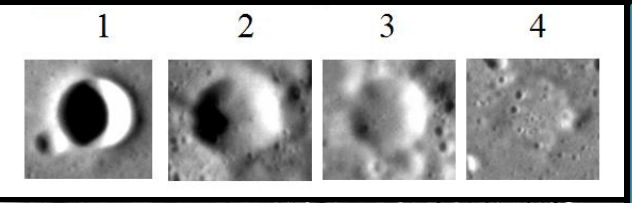
Compilation & Analysis

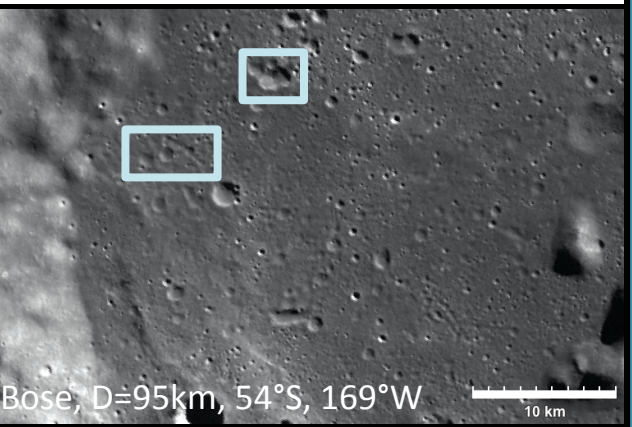
» Measure small superposed craters and assign degradation class (1-4) & obvious secondary (OS; clusters/chains) in JMARS

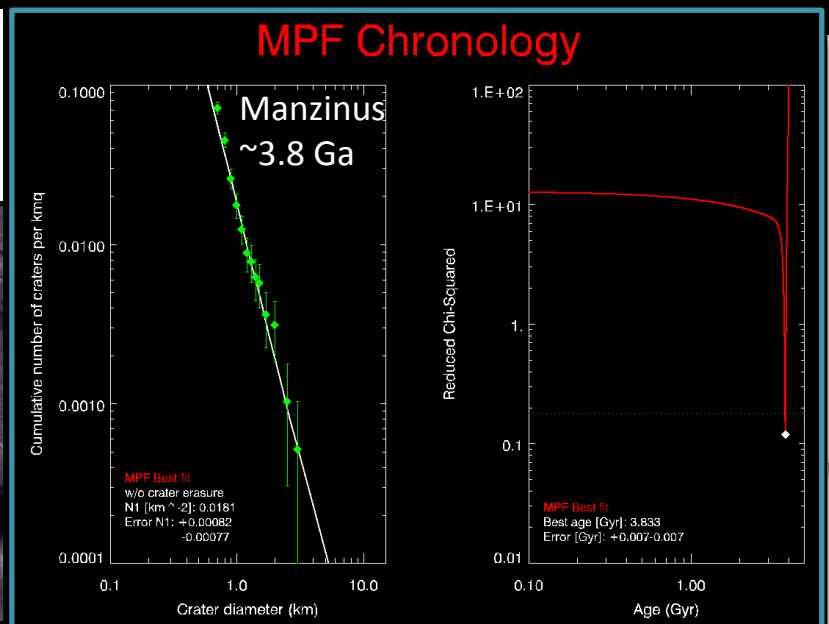
» Compute model ages with Marchi et al. (2009) Model Production Function (MPF)

» Compare small superposed crater SFDs to MPF

» Assign Stöffler et al. (2006) epoch & compare to past USGS identifications





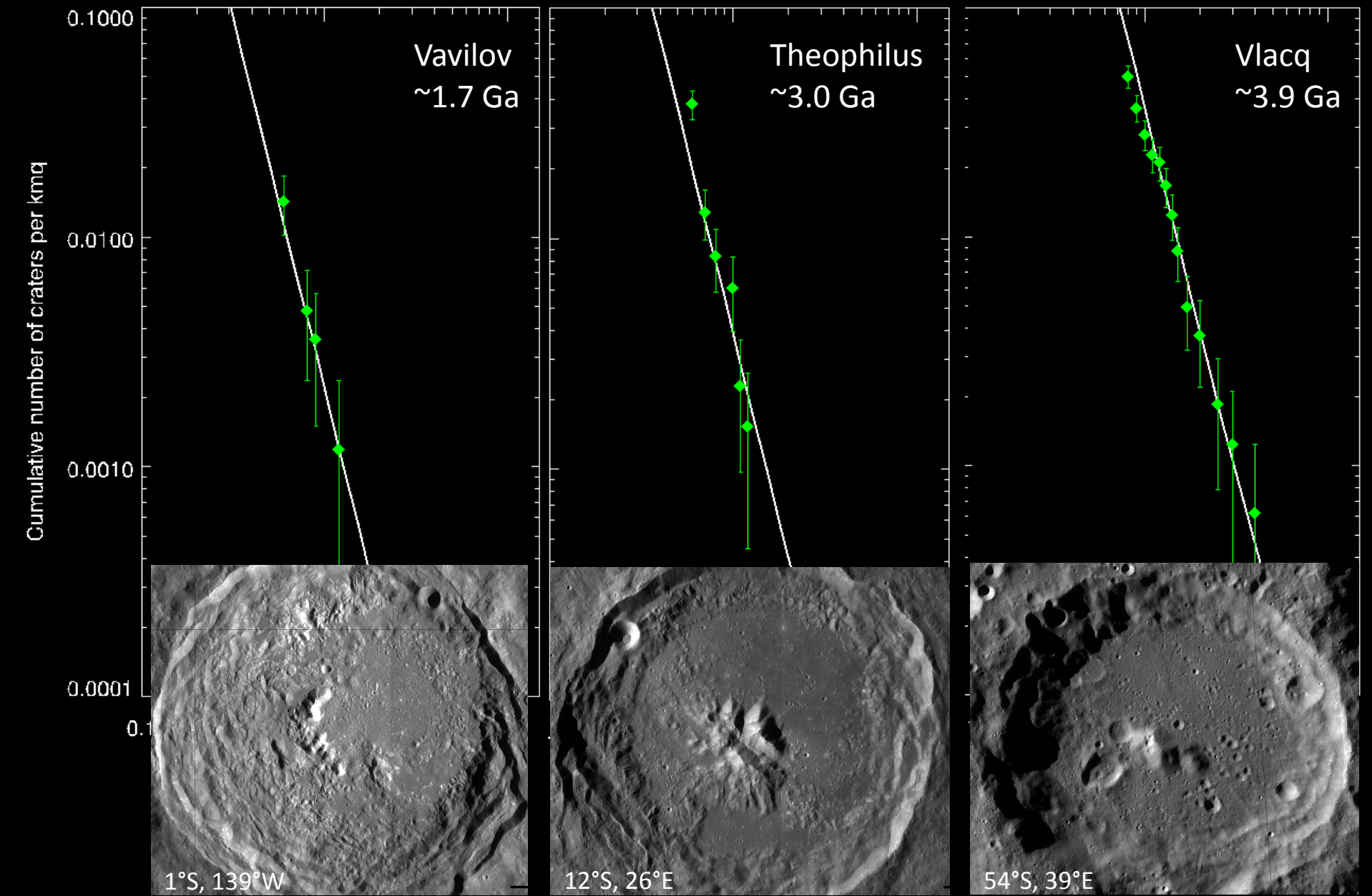


Stöffler et al. (2006)

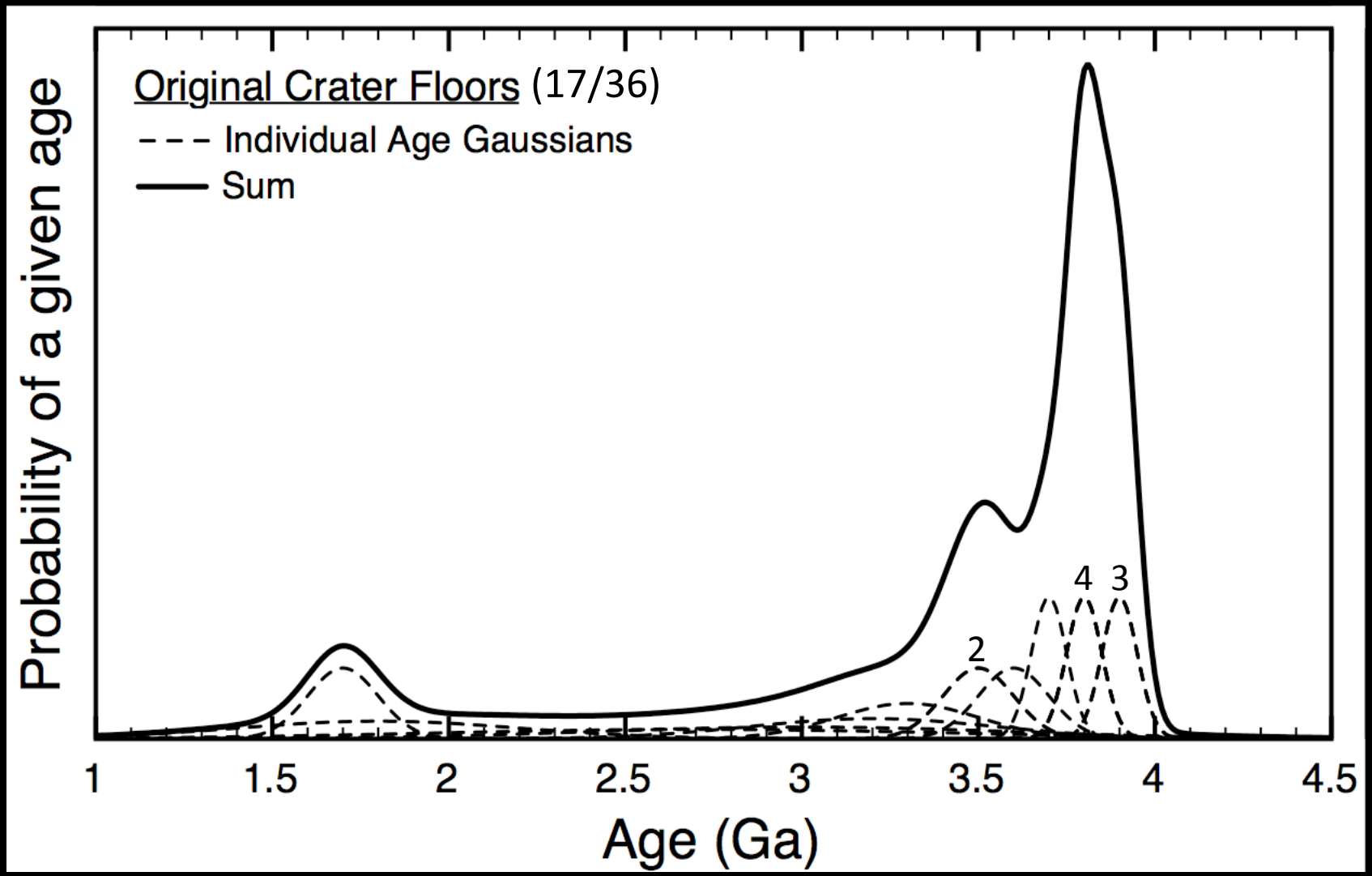
Proposed time periods for lunar time units

Time unit	Time (Gyr) options	Time (Gyr) adopted
Copernican Period	a) 2.1 - 0 b)1.0 - 0 c) 0.8 - 0	0.8 - 0
Eratosthenian Period	a) 3.2 - 2.1 b) 3.2 - 1.0 c) 3.2 - 0.8	3.2 - 0.8
Late Imbrian Period	a) 3.75 - 3.2 b) 3.72 - 3.2	3.75 - 3.2
Early Imbrian Period	a) 3.85 - 3.72 b) 3.85 - 3.75 c) 3.77 - 3.72 d) 3.77 - 3.75	a) 3.85 - 3.75 b) 3.77 - 3.75
Nectarian Period	a) 3.92 - 3.85 b) 3.92 - 3.77 c) 3.85 - 3.77	a) 3.92 - 3.85 b) 3.92 - 3.77
Pre- Nectarian Period	a) 4.52 - 3.92 b) 4.52 - 3.85	4.52 - 3.92

36/40 SSC SFDs are consistent with MPF



Crater Floor Model Ages



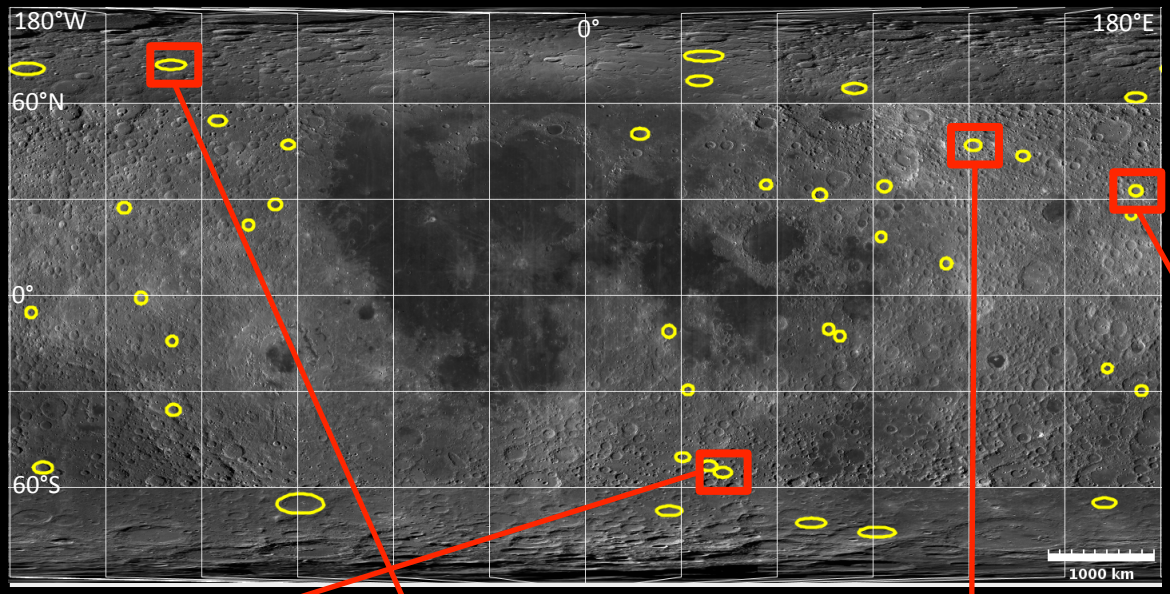
» Indicates LHB possibly ended with extended tail & little cratering < 2 Ga

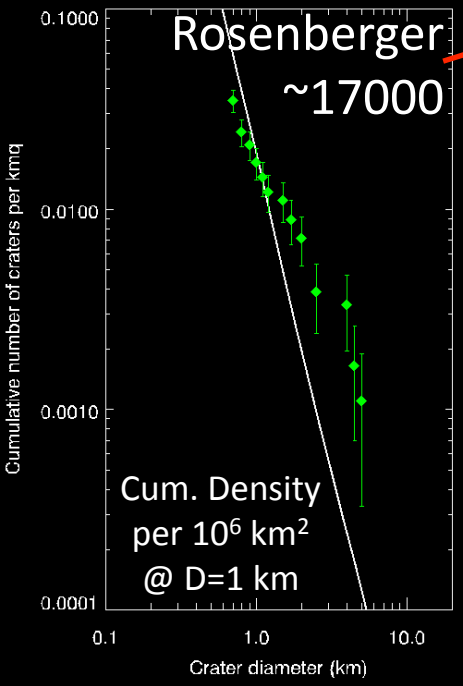
Crater Floor (CF) Model Ages

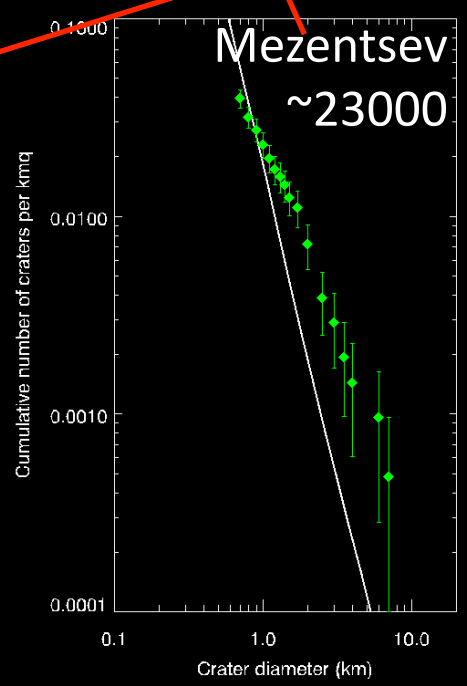
Crater Floor	Model Age	Associated Epoch (Stöffler et al., 2006)	Previous USGS Epoch
Vavilov	1.7 ± 0.1	Eratosthenian	Copernican
Hayn	1.8 ± 0.8	Eratosthenian	Copernican
Theophilus	3.0 ± 1.2	Eratosthenian	Copernican
Geminus	3.2 ± 0.7	Eratos./Imbr.	Eratosthenian
Hausen	3.5 ± 0.2	Late Imbrian	Eratosthenian
Robertson	3.7 ± 0.1	Late Imbrian	Copernican
Birkeland	3.8 ± 0.1	Early Imbrian	Eratosthenian
Lobachevskiy	3.8 ± 0.1	Early Imbrian	Late Imbrian
Hahn	3.8 ± 0.1	Early Imbrian	Late Imbrian
Arnold	3.8 ± 0.1	Early Imbrian	Late Imbrian
Baillaud	3.9 ± 0.1	Nectarian	Late Imbrian
Piccolomini	3.9 ± 0.1	Nectarian	Imbrian
Bridgman	3.9 ± 0.1	Nectarian	Imbrian
Vlacq	3.9 ± 0.1	Nectarian	Imbrian
Ansgarius	3.9 ± 0.1	Nectarian	Imbrian
Joule	4.0 ± 0.1	Pre-Nectarian	Imbr./Nect.
Laue	4.0 ± 0.1	Pre-Nectarian	Imbrian
Freundlich	4.0 ± 0.1	Pre-Nectarian	Imbrian
Neumayer	4.0 ± 0.1	Pre-Nectarian	Nectarian

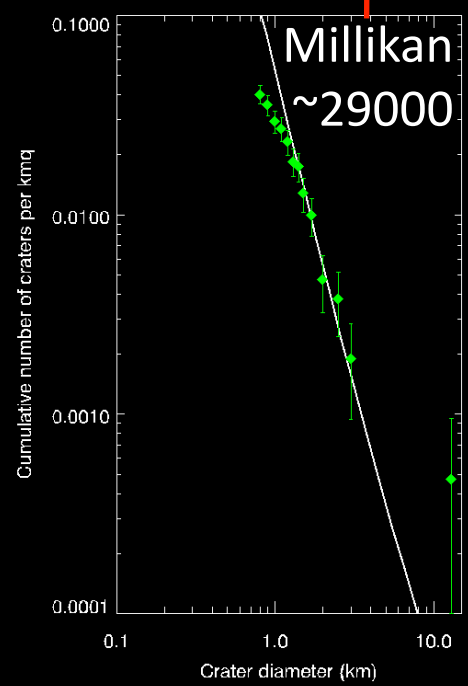
- For ~50% of CFs, our ages are older than previous
- Includes all formerly Copernican & Eratosthenian crater floors
- Issues with our data/ calculations?
- More interesting: issues w/ USGS interpretations and CFs are actually older?

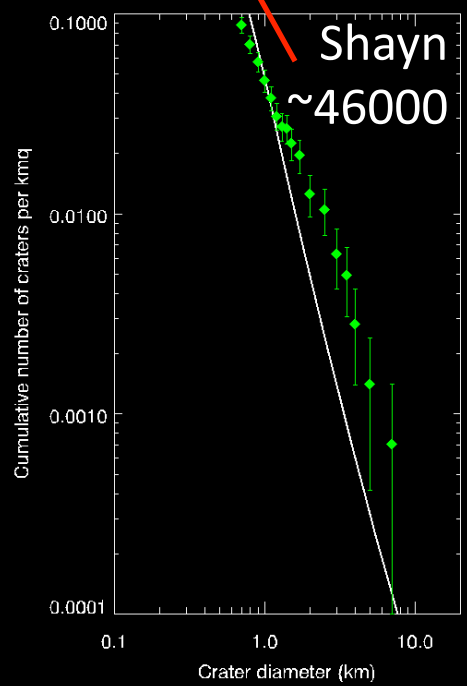
4/40 SSC SFDs NOT consistent w/ MPF





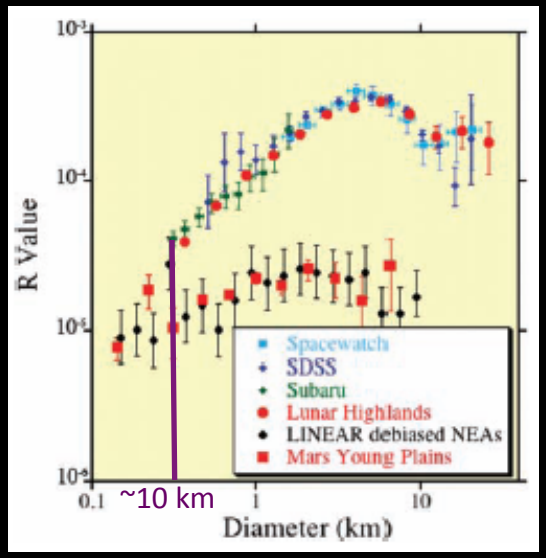






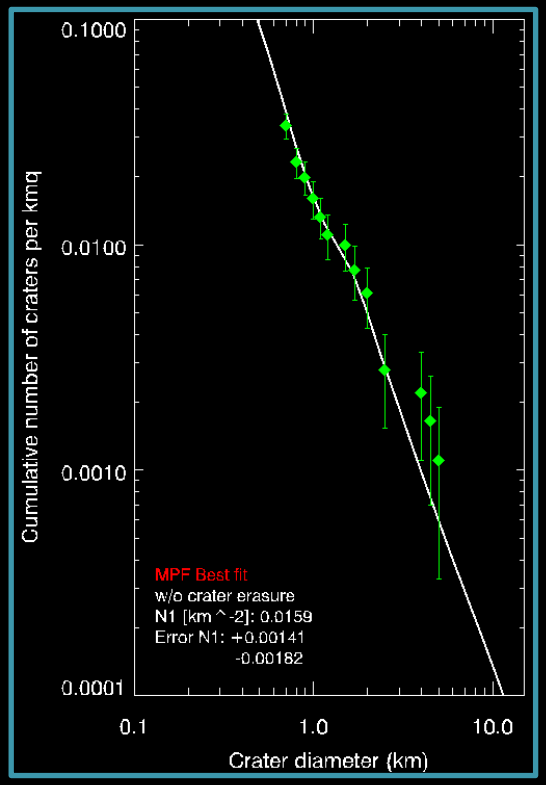
MPF Inputs Adjusted or SFD Geologically Modified?

Impactor



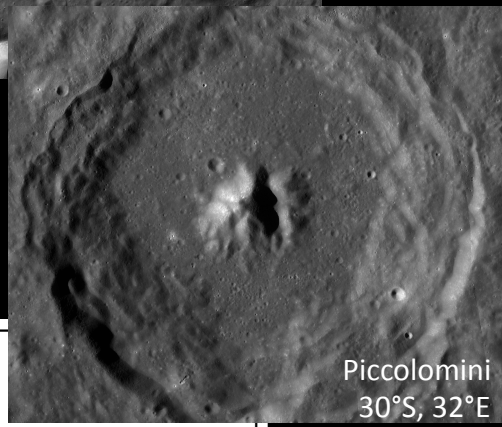
Population 1
Strom et al. (2001)

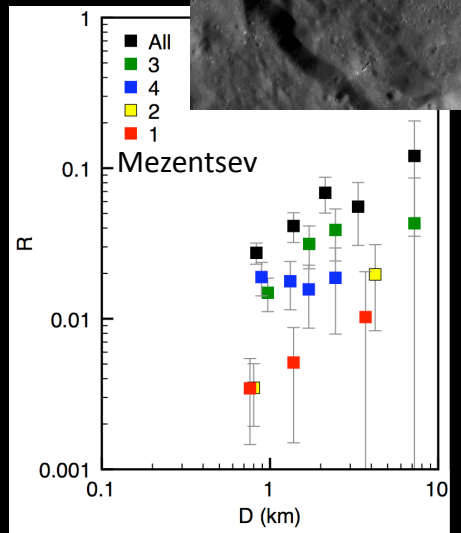
Scaling Law



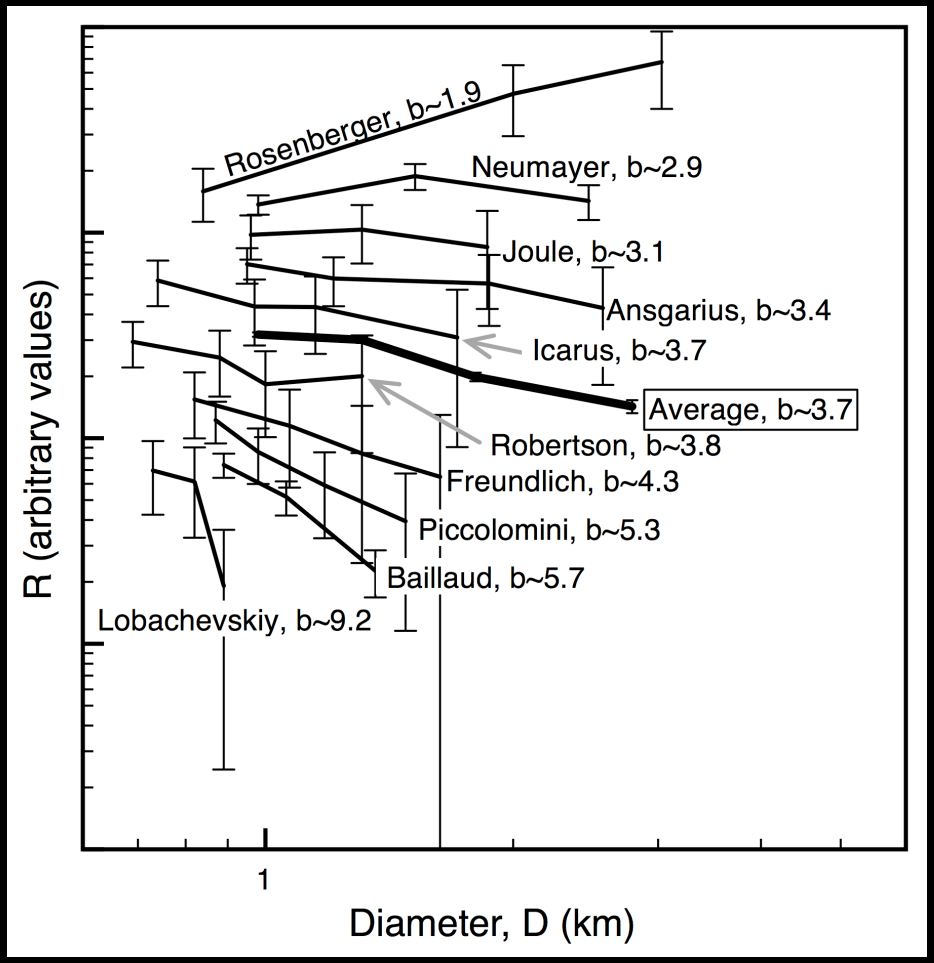
Rosenberger
w/ Layered Scaling Law
Marchi et al. (2011)

Resurfacing





Obvious Secondaries



» Wide variation in obvious secondary SFD slopes

» Related to formation of individual secondary crater fields?

Conclusions

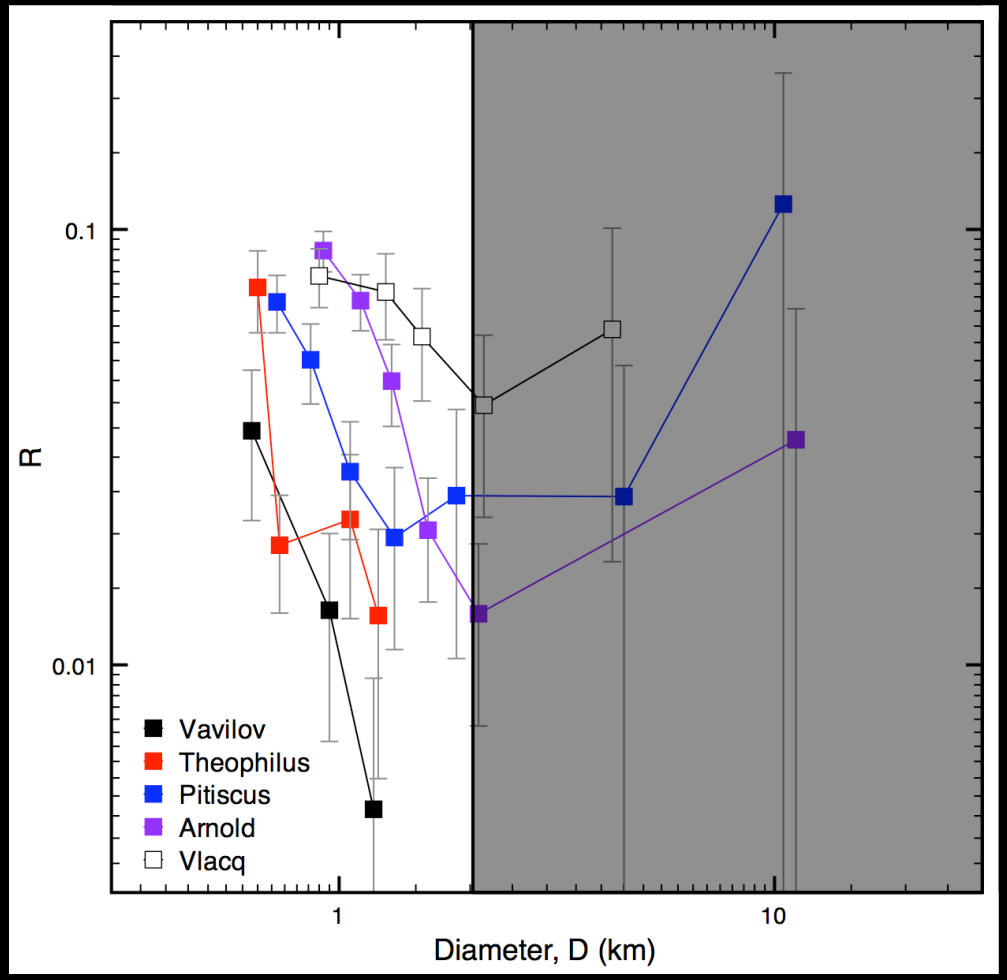
- Agreement between most of SSC SFDs and MPF further validates MPF & indicates SSC SFDs are likely largely characterized by primary craters
- Model ages of original CFs indicate LHB had an extended tail
- Ages older than initially ascertained => may be less cratering during Copernican/Early Eratosthenian (< 2 Ga) than originally thought
- Few SSC SFDs not consistent with MPF => Likely modified by geologic activity, but MPF inputs can be adjusted to fit; is this appropriate?
- Obvious secondary SFDs have widely varying slopes that likely are representative of different types of secondary cratering

Acknowledgments: NLSI for funding support, JMARS support team, and my co-authors

SSC SFD Unchanging?

D < 3 km
Yes

=> Impactor SFD slope remain stable over 1-4 Ga?

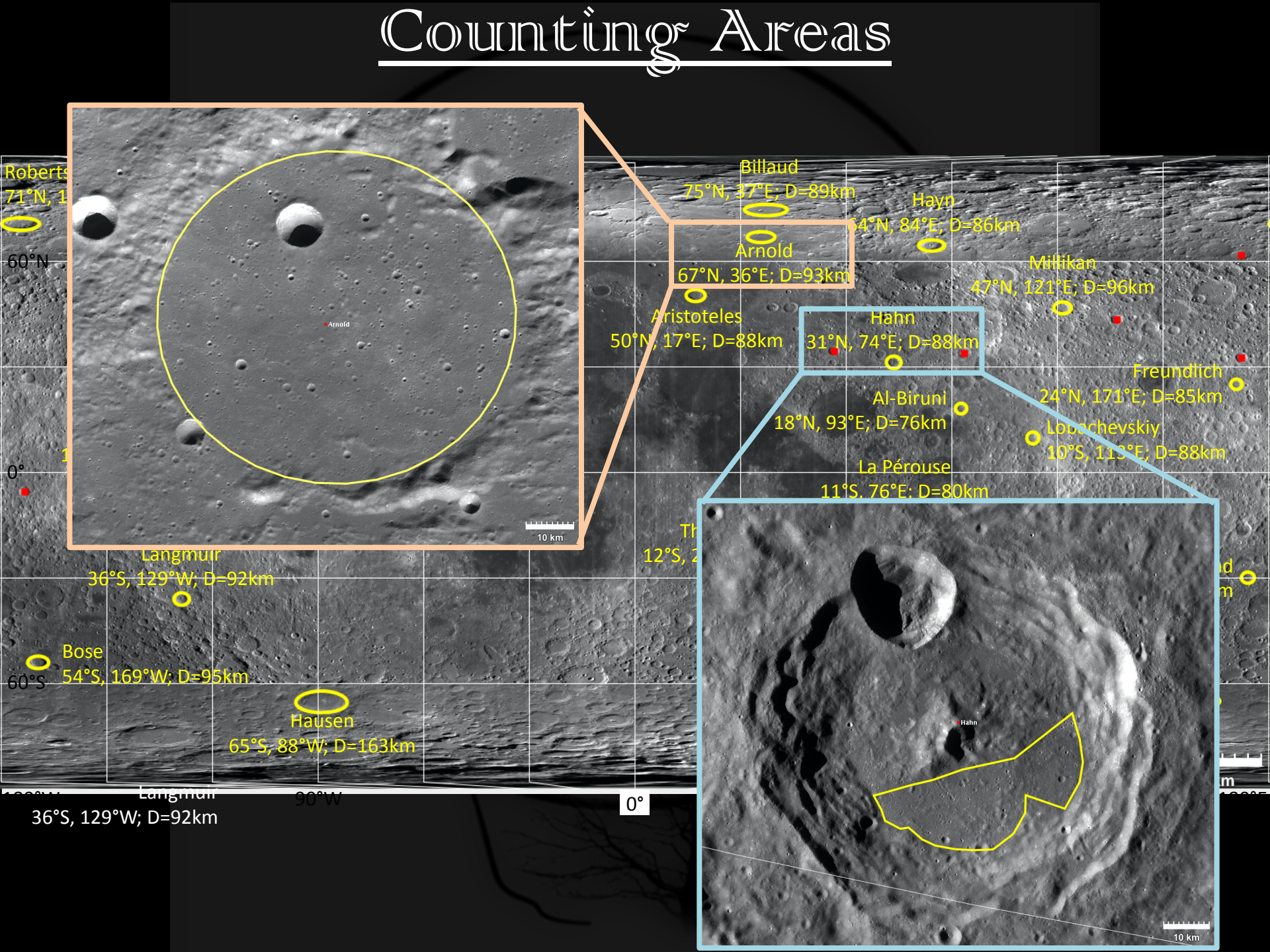


D > 3 km
??

Poor statistics: approaching size of counting areas

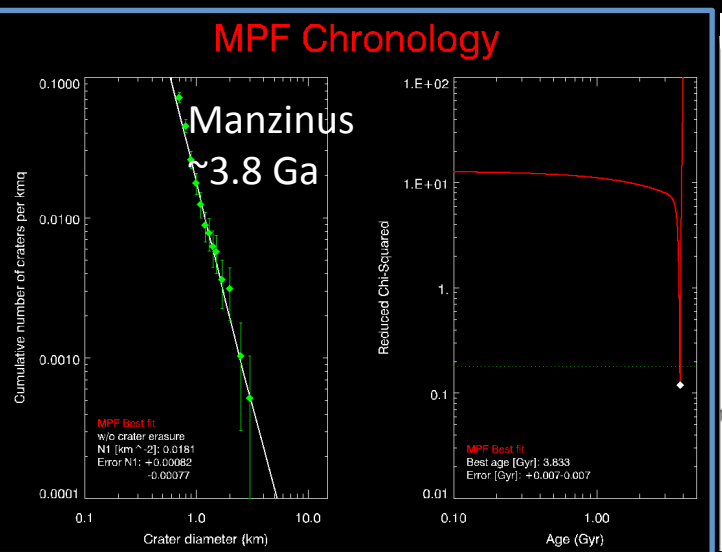
Trend: transition to shallower slopes??

Counting Areas



36°S, 129°W; D=92km

Analysis



Stöffler et al. (2006)

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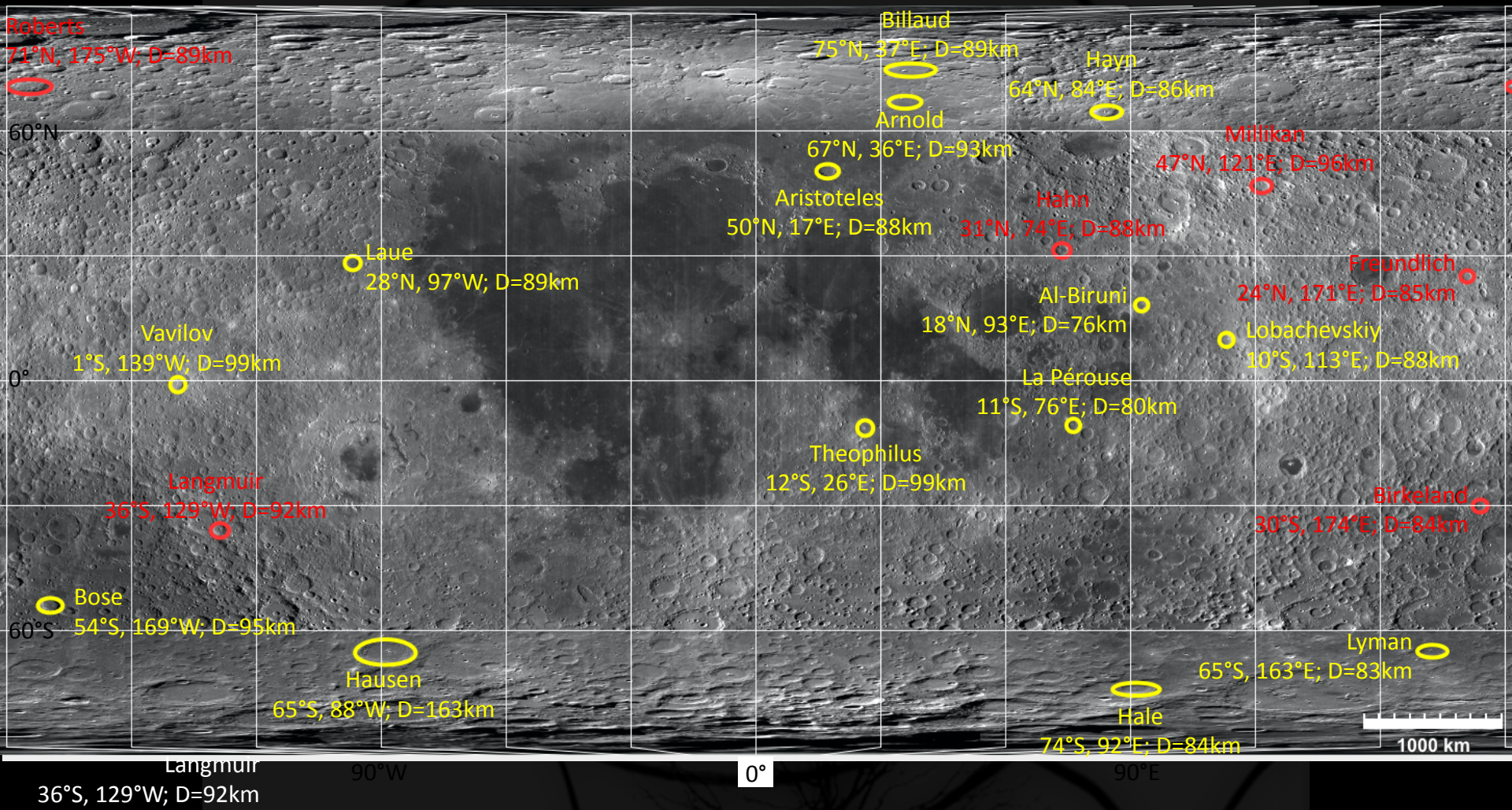
SFD Interpretations - Age

Crater	Relative Age	Absolute Age	Stöffler Epoch	USGS Epoch
Hayn	1800 ± 1000	1.1 ± 0.2	Cop./Erat.	Copernican
Vavilov	3600 ± 2100	1.3 ± 0.2	Cop./Erat.	Copernican
Aristoteles	6200 ± 1800	3.5 ± 0.2	Late Imbrian	Eratosthenian
Theophilus	7100 ± 2000	3.4 ± 0.2	Late Imbrian	Copernican
Hale	7400 ± 2800	3.6 ± 0.1	Late Imbrian	Late Imbrian
Hausen	7600 ± 900	3.6 ± 0.1	Late Imbrian	Eratosthenian
Lyman	8300 ± 2400	3.6 ± 0.1	Late Imbrian	Late Imbrian
La Pérouse	10000 ± 2800	3.7 ± 0.1	Late Imbrian	Late Imbrian
Roberts	13600 ± 2500	3.8 ± 0.2	Early Imb./Nect.	Early Imb./Nect.
Langmuir	15500 ± 3900	3.8 ± 0.1	Early Imb./Nect.	Early Imbrian
Arnold	16000 ± 1900	3.8 ± 0.1	Early Imb./Nect.	Early Imbrian
Bose	16500 ± 2500	3.8 ± 0.2	Early Imb./Nect.	Early Imbrian
Lobachevskiy	17200 ± 3100	3.9 ± 0.1	Nectarian	Late Imbrian
Birkeland	18800 ± 4200	3.9 ± 0.2	Nectarian	Eratosthenian
Hahn	19400 ± 5400	3.9 ± 0.1	Nectarian	Late Imbrian
Al-Biruni	19800 ± 3300	3.8 ± 0.1	Early Imb./Nect.	Early Imbrian
Laue	25000 ± 3900	3.9 ± 0.2	Nectarian	Early Imbrian
Baillaud	25600 ± 2300	3.9 ± 0.1	Nectarian	Early Imbrian
Millikan	25800 ± 3100	4.0 ± 0.1	Pre-Nectarian	Early Imb./Nect.
Freundlich	26300 ± 3800	3.9 ± 0.1	Nectarian	Early Imbrian

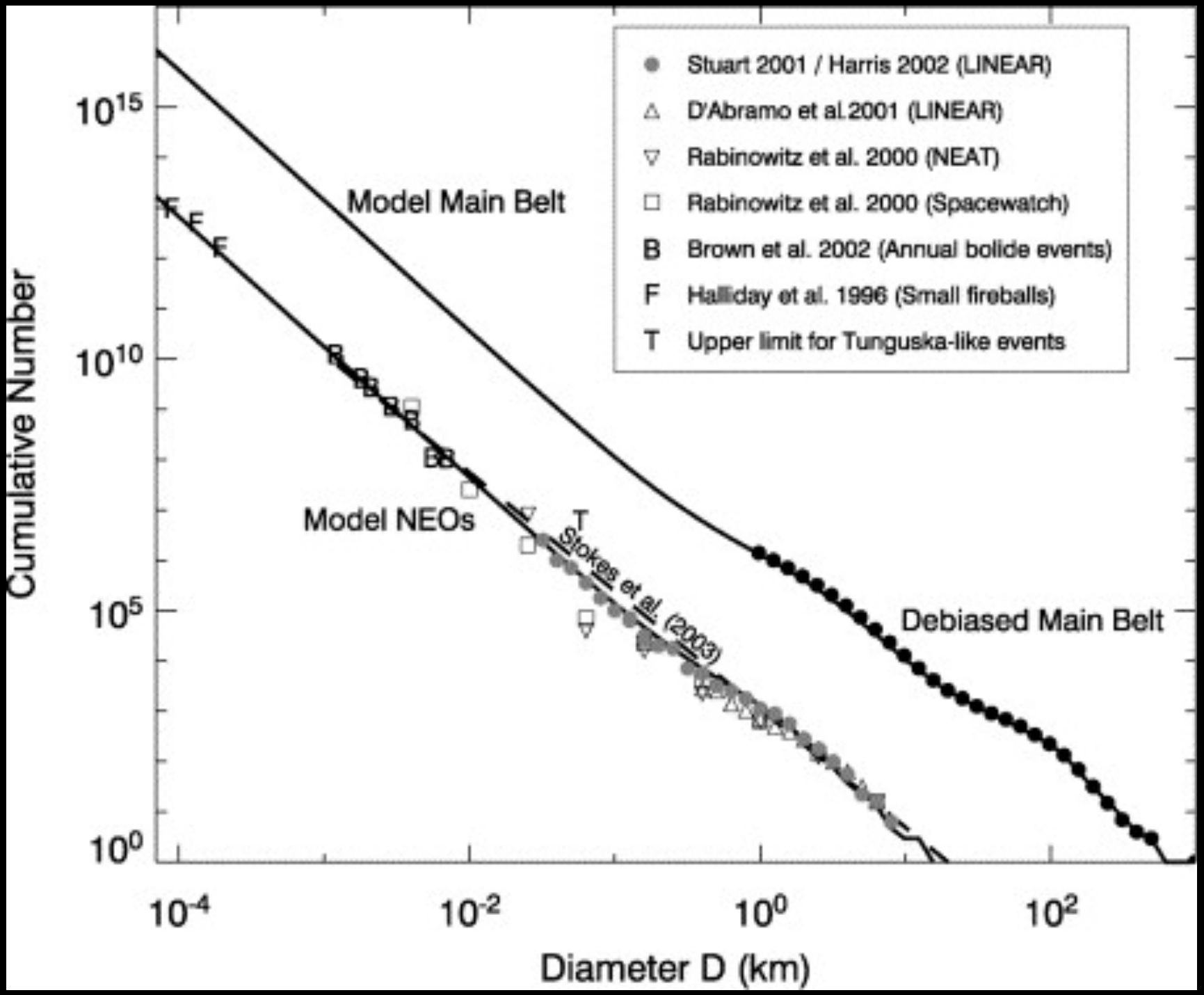
- SFDs that match MPF (black) have wide age distribution
- SFDs that are shallower than MPF (red) all relatively old

SFD Interpretations – Distribution



Langmuir
36°S, 129°W; D=92km

- SFDs that match MPF (yellow) appear widely distributed in latitude & longitude
- Majority of SFDs that are shallower than MPF (red) on farside – pattern??


Stuart 2001 / Harris 2002 (LINEAR)
D'Abramo et al.2001 (LINEAR)
Rabinowitz et al. 2000 (NEAT)
Rabinowitz et al. 2000 (Spacewatch)
B Brown et al. 2002 (Annual bolide events)
F Halliday et al. 1996 (Small fireballs)
T Upper limit for Tunguska-like events
Model Main Belt
Model NEOs
Stokes et al. (2003)
Debiased Main Belt
Cumulative Number
Diameter D (km)
10^{15}
10^{10}
10^{5}
10^{0}
10^{-4}
10^{-2}
10^{0}
10^{2}